Wine Grape Response to Kaolin Particle Film under Deficit and Well-Watered Conditions

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Abstract

Kaolin particle film was developed to reduce heat stress and improve water use efficiency in perennial fruit crops. A study was done to determine how the film impacts water relations of wine grape (*Vitis vinifera* L.) cultivars 'Viognier' and 'Merlot' grown without rootstock in the high desert region of southwestern Idaho. Vines were either sprayed with kaolin or unsprayed (control) and either well-watered at 100% estimated crop evapotranspiration (ET_c), or deficit-irrigated at 35% ET_c until veraison followed by 70% ET_c until harvest. As expected, kaolin reduced leaf temperature under both irrigation regimes. However, a reduction in stomatal conductance and less negative leaf water potential values for kaolin-treated vines were observed only under well-watered conditions. Lack of response to kaolin under deficit water conditions was probably due to a water-stress-induced increase in stomatal closure that was independent of leaf temperature. When leaf temperature difference between kaolin and non-kaolin sprayed leaves was at its daily maximum, deficit-irrigated vines had already reached their minimum or most negative values for stomatal conductance and leaf water potential, but values for well-watered vines had just begun to change. Kaolin had no effect on canopy total light interception, pruning weight, yield, berry titratable acidity or soluble solids concentration, though cluster weight of well-watered, kaolin-sprayed 'Viognier' was larger than well-watered non-kaolin 'Viognier' vines. The leaf water potential of 'Merlot' was more responsive to diurnal changes in vapor pressure deficit than 'Viognier' yet neither showed a response to foliar kaolin application under deficit irrigation. Better understanding of the mechanism by which kaolin film increases water use efficiency will provide insight as to the relative roles of plant hormones, evaporative demand, and plant water status on leaf gas exchange and facilitate determination of its potential for enhancing production efficiency of wine grapes in arid regions.

INTRODUCTION

Deficit irrigation strategies have been developed to optimize fruit quality for wine production (Jackson and Lombard, 1993; Kriedemann and Goodwin, 2003). However, under certain climatic conditions, deficit irrigation may increase the incidence of undesirable sunscald and heat stress. Application of kaolin-particle film to the leaf or fruit surface has been shown to reduce heat stress without restricting gas exchange (Glenn et al., 2001). The leaf intercepts photosynthetically active radiation through the particle film, while the film reflects ultraviolet and infrared radiation from the leaf or fruit surface (Glenn and Puterka, 2005). Kaolin-particle film has been associated with increased water use efficiency in citrus (Jifon and Syvertsen, 2003), but decreased water use efficiency in apple (Glenn et al., 2003), suggesting an interaction of the film by species or by other climatic or edaphic factors. The purpose of this study was to examine how kaolin-particle film impacts the leaf water potential, leaf temperature, and leaf gas exchange of a red and a white wine grape cultivar under well-watered or deficit irrigated conditions.

MATERIALS AND METHODS

The trial was established on 6-year-old vines (cultivars 'Viognier' and 'Merlot') planted in north to south oriented rows on a 3-7% slope with northern aspect. Row by vine spacing was 2.7 by 2.1 m (1764 vines/ha). Each vine was double trunked, with each trunk forming a unilateral, 90 cm long cordon located 1 m above the soil surface. Cordon arms were spur pruned (seven, two-bud spurs per cordon) and vertically trained using two sets of moveable wires. The soil type was a fine sandy loam. The trial contained four blocks with three rows per block and 56 vines per row, and each block had an independently controlled irrigation delivery system that included a programmable controller (Nelson model 8071, SoloRain Peoria, IL, USA), solenoid valve (Nelson model 8032 SoloRain, Peoria, IL, USA), and in-line flow meter (Master Meter Multijet, Mansfield, TX, USA). Supplemental water was provided to vines by above-ground drip with two, punch-in, pressure-compensating, 3.8 L h^{-1} emitters located 15 cm on either side of each vine trunk. Irrigation duration was scheduled to provide either 100% of estimated crop evapotranspiration (ET_c) from fruit set until harvest, or 35% ET_c from fruit set until veraison followed by 70% ET_c until harvest. Application efficiency was assumed to be 100% for all treatments and replications. Vines were irrigated twice weekly and irrigation amount was calculated from published reference evapotranspiration based on alfalfa (U.S. Bureau of Reclamation Nampa weather station http://www.usbr.gov/pn/agrimet/wxdata.html), a wine grape crop coefficient (Evans et al., 1993) which varied from 0.2 to 0.7 during the season, multiplied by the desired percentage of ET_c. The irrigation treatments were independently allocated to field blocks with a single block replication. The soil was irrigated to around field capacity before bud break and after leaf fall, and as needed between bud break and fruit set to maintain vine midday leaf water potential (Ψ_{md}) above -1.0 MPa. Differential irrigation regimes were initiated after fruit set.

Subplots established within each block contained four kaolin particle film-treated and four non-particle film-treated vines per cultivar. The particle film was applied with a backpack sprayer at a rate of 60 g/L. The first foliar application was after fruit set (July 6, 2005) and contained 1.3 ml per liter of a nonionic surfactant. Subsequent foliar applications did not contain a surfactant, and were applied preveraison (July 11, July 18), and post-veraison (August 8). Control vines received no spray application.

Vine water status was monitored weekly by measuring Ψ_{md} two days after irrigation. Two fully exposed, mature leaves showing no visible sign of damage were randomly selected from interior vines of each subplot one to two hours after solar noon. Leaves were covered with a clear plastic bag before severing the petiole at the point of shoot attachment, and the bag containing the leaf was immediately inserted into a pressure chamber (PMS Instruments model 610, Corvallis, OR USA). The chamber was pressurized at a rate of 33 kPa s^{-1} and balancing pressure recorded at the first appearance of moisture on the cut petiole. Diurnal stomatal conductance, leaf surface temperature (LI-1600 Steady State Porometer, LiCor, Lincoln Nebraska, USA) and Ψ_{md} were measured hourly on four leaves in each subplot. Measurements in 'Merlot' and 'Viognier' vines were taken on DOY 215 (2 weeks before veraison) and DOY 236 (6 days after veraison), respectively.

Yield per vine, and average cluster weight were measured by counting and weighing all clusters per vine and dividing crop weight by number of clusters. Berry weight, and must composition were determined at harvest from a sample of 5 clusters harvested from the east and west side of each subplot. Two berries from each of five cluster locations (four cardinal quadrants and center) were removed from each cluster and weighed to calculate 100-berry weight. The remaining berries in the 10-cluster sample were passed through a hand operated crusher, left overnight on the skins at room temperature, and analyzed the following day for percent soluble solids (digital bench top refractometer Mettler Toledo RE40, Columbus, OH, USA), pH, and titratable acidity (Brinkmann Metrohm 716 DMS Titrino autotritrator, Switzerland).

Data describing berry and vine attributes were analyzed separately by cultivar

using analysis of variance appropriate for a block design (General Linear Model, SAS version 8.02; SAS Institute, Cary, NC, USA) with irrigation and particle film technology as main effects. Probability of significant difference among treatments was determined from an F test. Significant irrigation treatment means were separated using Duncan's multiple range test ($p < 0.05$).

RESULTS AND DISCUSSION

Irrigation regime had a greater impact on leaf surface temperature, leaf water potential, leaf gas exchange, and yield components than did application of kaolin particle film, and the effect of particle film varied according to irrigation regime and or cultivar. The leaf surface temperature of well-watered 'Viognier' and 'Merlot' vines was 2.7 and 2.9°C cooler, respectively, than deficit irrigated vines. Kaolin treated leaves within each irrigation regime were 1.5 and 1.7°C cooler than non-kaolin treated leaves (well-watered and deficit vines, respectively). The diurnal onset and duration of the kaolin-associated cooler leaf temperature was affected by irrigation regime. Kaolin treated leaves under deficit irrigation were cooler earlier in the day, but remained cooler for less time than kaolin-treated leaves under well-watered conditions. Well-watered, kaolin-treated leaves were cooler than similarly irrigated, non-kaolin leaves in 75% and 80% ('Merlot' and 'Viognier', respectively) of all hourly readings, while deficit irrigated, kaolin-treated leaves were cooler in 68% and 67% (Merlot and Viognier, respectively) of all hourly readings.

Well-watered vines had less negative leaf water potential and higher stomatal conductance than deficit irrigated vines. Particle film had less impact than irrigation regime on leaf water potential and stomatal conductance, and its effect appeared to vary by irrigation regime and cultivar. Prior to noon, well-watered vines with particle film had less negative leaf water potential and lower stomatal conductance than well-watered vines without particle film. The leaf water potential of well-watered, 'Merlot' vines with particle film remained less negative a few hours longer than similarly-treated, 'Viognier' vines. In the afternoon, when kaolin associated cooling was most pronounced, well-watered, particle film treated vines showed higher stomatal conductance and less negative leaf water potential values than similarly irrigated non-particle film treated vines. Vines under deficit irrigation with particle film had more negative ('Viognier') or similar ('Merlot') leaf water potential and lower ('Viognier') or similar ('Merlot') stomatal conductance as similarly irrigated, non-particle film treated vines.

Weekly midday leaf water potential (Ψ_{md}) throughout the growing season corresponded with irrigation regime. Well-watered vines had less negative Ψ_{md} than deficit irrigated vines, and the Ψ_{md} of deficit irrigated vines was less negative at veraison when irrigation amount increased from 35% to 70% ET_c. The difference between irrigation regimes in Ψ_{md} was greater than the difference between particle film treatments within each irrigation regime. Well-watered vines with particle film had less negative Ψ_{md} than non-particle film vines in 75% and 80% of the sampling dates for 'Merlot' and 'Viognier', respectively. However, under deficit irrigation, particle film vines had less negative Ψ_{md} than non-particle film vines on 25% and 10% of the sampling dates for 'Merlot' and 'Viognier', respectively.

Irrigation regime impacted the yield components of both cultivars and the titratable acidity of 'Viognier' (Table 1). Vines under deficit irrigation had 39% and 49% lower yield per vine, 35% and 32% lower cluster weight, and 12 and 15% lower berry weight for 'Merlot' and 'Viognier', respectively, than well-watered vines. All treatments had similar soluble solids concentration and pH at harvest (25% and 22% Brix and pH 3.4 and 3.1, for 'Merlot' and 'Viognier', respectively). The juice titratable acidity of deficit-irrigated 'Viognier' was lower than well-watered vines. Well-watered, 'Viognier' vines with particle film had 15% greater cluster weight than similarly irrigated, non-particle film vines, but this trend was not observed in 'Merlot'.

Results from this trial show a strong influence of the soil-plant-air water continuum as well as genotype on vine response to kaolin particle film. In this study we

observed greater reduction in leaf temperature between irrigation regimes than between particle treatments and the reduction in leaf temperature observed between irrigation regimes was of similar magnitude others have observed for kaolin particle film on apple (Glenn et al., 2001) and citrus (Jifon and Syvertsen, 2003). One explanation for why we observed less impact on leaf temperature of particle film relative to irrigation could be attributed to the more arid climate, high elevation (750 m) and high solar radiation of our evaluation site. Vine response to kaolin particle film appears to be driven by a reduction in the leaf-to-air vapor pressure difference that results from a cooler leaf surface. The morning decrease and afternoon increase in stomatal conductance of kaolin relative to non-kaolin leaves under well-watered conditions in this study was also observed in kaolin-treated citrus (Jifon and Syvertsen, 2003). Under well-watered conditions, the reduction in leaf temperature from the particle film lowered the leaf-to-air vapor pressure gradient. This lower leaf-to-air vapor pressure gradient most likely lowered transpiration rate and stomatal conductance resulting in less negative leaf water potential. Onset of the daily depression in leaf water potential and stomatal conductance was delayed in well-watered, kaolin-particle film treated vines, most likely due to cooler leaves with a reduced leaf-to-air vapor pressure gradient. A lack of response to cooler leaf temperature under deficit irrigation suggests that stomatal responsiveness was limited by low plant water status. The different diurnal pattern of leaf water potential of 'Viognier' and 'Merlot' provides further evidence that genotype impacts plant response to water stress, and supports the near-isohydric and near-anisohydric models described by Schultz (2003) and further investigated by Soar et al. (2006). The increase in cluster weight observed for well-watered, kaolin-treated 'Viognier' suggests that near-isohydric type cultivars may be more responsive to the reduced leaf-to-air vapor pressure gradient provided by particle film application.

CONCLUSIONS

Foliar application of kaolin particle film reduced leaf temperature under both well-watered and deficit irrigation regimes. However, lower stomatal conductance and less negative leaf water potential values for kaolin-treated vines was observed only under well-watered conditions. Lack of response to kaolin under deficit water conditions was probably due to a water-stress-induced increase in stomatal closure that was independent of leaf temperature. Further study is needed to speculate whether kaolin sprays could improve production efficiency or grape quality in arid production regions.

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Tables

Table 1. Yield components and titratable acidity of 'Merlot' and 'Viognier' under two irrigation treatments (100% and 35-70% ET_c) with (+) or without (-) kaolin particle film (PF) during the experiment conducted in Parma, Idaho, USA.

	Titratable acidity (g/L)	100 Berry weight (g)	Yield per vine (kg)	Cluster Weight - PF (g)	Cluster Weight +PF (g)
			Merlot[z]		
100% ET_c	5.2	116.2a	3.1a	103.2a	
35-70% ET_c	5.2	102.2b	1.9b	66.8b	
Irrigation	ns[y]	*	*	**	
Particle film	ns	ns	ns	ns	
Irrigation x film[x]	ns	ns	ns	ns	
			Viognier[z]		
100% ET_c	9.1a	102.6a	5.3a	120.9b	138.6a
35-70% ET_c	7.3b	87.2b	2.7b	88.3c	88.6c
Irrigation	**	**	*	**	
Particle film	ns	ns	ns	*	
Irrigation x film[x]	ns	ns	ns	*	

[z] Mean separation within columns for a cultivar by protected LSD, *P=0.05*

[y] No significant difference, (P>0.05).

[x] When an irrigation by PF interaction was significant (**), the individual treatments were separated using a protected LSD, *P=0.05*.